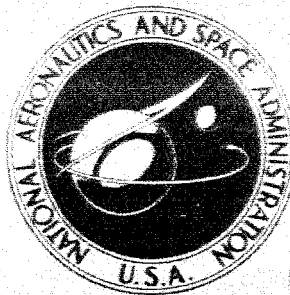


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A LIGHTWEIGHT FOLDING BOOM
FOR ACCURATELY PLACING
SCIENTIFIC EXPERIMENTS UP TO
25 FEET FROM LARGE SPACECRAFT

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NASA
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SUMMARY

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A feasibility study was conducted on large folding booms for spacecraft applications. The resulting design featured precise repeatability, permitted the passing of a large electrical cable directly through each knuckle, and used a constant-speed spring-driven motor to operate the knuckles by means of a cable. The entire assembly, including the spring motor, is completely non-magnetic and is ideally suited for placing a magnetometer experiment a considerable distance from the spacecraft structure. It can also place many other instruments, such as antennas and solar-celled paddle systems, away from the structure.

AUTHOR

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A LIGHTWEIGHT FOLDING BOOM FOR ACCURATELY PLACING SCIENTIFIC EXPERIMENTS UP TO 25 FEET FROM LARGE SPACECRAFT

(Manuscript Received July 8, 1963)

by

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INTRODUCTION

Certain experiments flown on spacecraft are susceptible to contamination or interference by the spacecraft operational system, by other experiments, or by both of these. One way to overcome this problem without imposing undue restrictions on other spacecraft components is to place the sensitive experiment some distance from the main body. If the required separation is much longer than the body of the spacecraft, the use of a multisection boom appears logical. This report presents the results of a study to develop a folding boom explicitly for such applications (Figure 1).

DESIGN CRITERIA

This boom system was designed to meet the non-magnetic, high strength, and alignment requirements imposed by several experiments and it incorporates the following features:

1. Power to unfold the boom in subzero temperatures, with a large electrical cable passing through the knuckle;
2. Slow speed, approximately $1/2$ rpm for each joint, to prevent whiplash of the experiment when the last section of the boom opens;
3. Positive locking of the knuckles to prevent any relative motion after closing, and repeatability of the closing position to give the highest degree of accuracy possible;

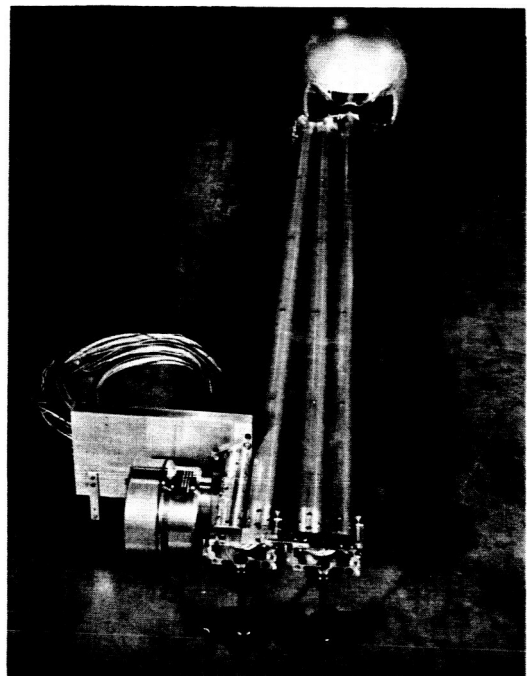


Figure 1—A 12 foot experimental folding boom in folded condition with a hermetically sealed, nonmagnetic spring motor.

4. Reliability through simple design and redundancy where possible;
5. Exclusive use of nonmagnetic materials;
6. Flexibility in conforming to the spacecraft shape and allowable volume under the shroud;
7. Easy adaptability to any desired unfolding sequence.

BOOM OPERATION

The sequence of events for erecting the boom are initiated by an electric impulse from the spacecraft which starts the motor. The motor unfolds the boom by reeling in, at a constant speed, a wire cable which applies a high torque to each joint. This cable is fastened to the last section of the boom, goes around a pulley in each knuckle, and is fastened to a reel on the motor. The pulley in each joint is free to rotate, so that the cable can move easily when other knuckles are closing.

With the motor started, the normal sequence is the successive opening of each joint beginning with the one closest to the spacecraft. As one knuckle closes and locks, the next section unfolds. A microswitch in each knuckle signals when the joint is closed and turns off an electric drive motor (if one is used) when the boom is fully opened. If a spring motor is used the motor stalls when the boom is fully deployed.

BOOM CONFIGURATION

The boom can be designed in almost any configuration or length to adapt to the spacecraft body and booster fairing. The sequencing of knuckle operation can be in any order, even to the point of having a joint close in steps with other knuckles closing between these steps. This would be done to prevent the experiment from hitting the boom or spacecraft while unfolding. An example of this is illustrated in Figure 2 where the first knuckle has closed and the second is about to lock. However, the third knuckle has already opened a sufficient distance to prevent the sphere from hitting the first section of the boom as the second knuckle closes. This opening of the third knuckle occurred when the motor was started, but further motion has been restricted by a cable to the sequencing device on the second knuckle. Figure 3 shows the boom fully deployed.

Possible variations of the boom configuration include:



Figure 2—Boom deploying. This illustrates the feature which prevents an experiment from hitting the boom during opening.

1. The motor can be mounted inside the spacecraft, on the boom before the first knuckle, or on any other section of the boom;
2. The sections need not be of the same length;
3. The sections do not have to be folded in the same plane.

TRIGGERED KNUCKLE LOCK

Figures 4, 5, and 6 show the details of another feature of the boom. The accuracy of this unique lock is not dependent on the clearance allowed for the knuckle pivot, or on the precise location of any of its parts; yet it will repeatedly lock the knuckle in the same position and prevent any relative movement between the knuckles of a joint.

The operation sequence of the triggered knuckle lock starts when the joint is almost closed and "B" knuckle pushes the trigger in "A" knuckle. When the trigger pin is withdrawn from between the spring

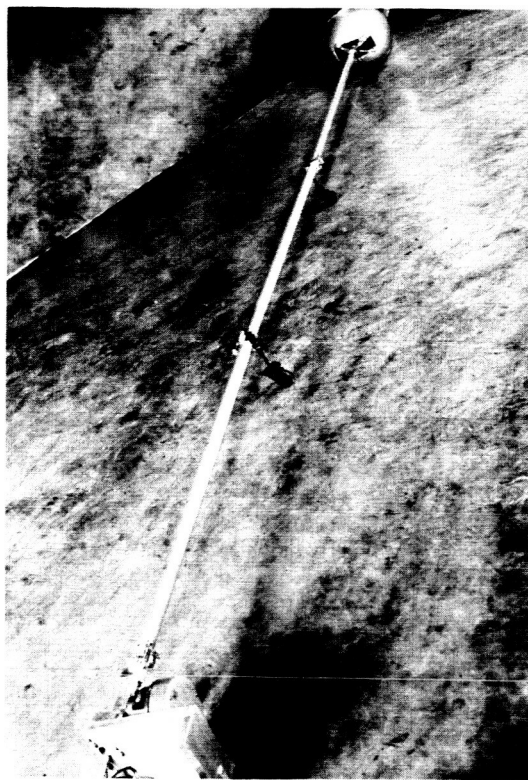


Figure 3—Boom fully deployed.

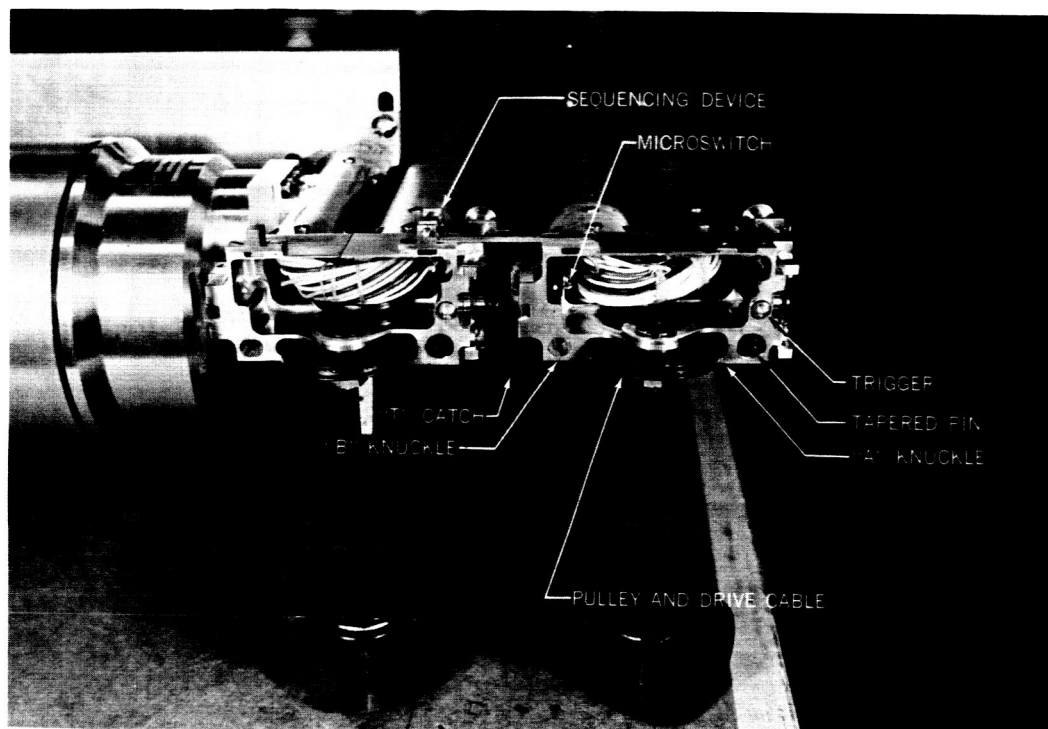


Figure 4—Details of the triggered knuckle lock and internal passage of the electrical cable.

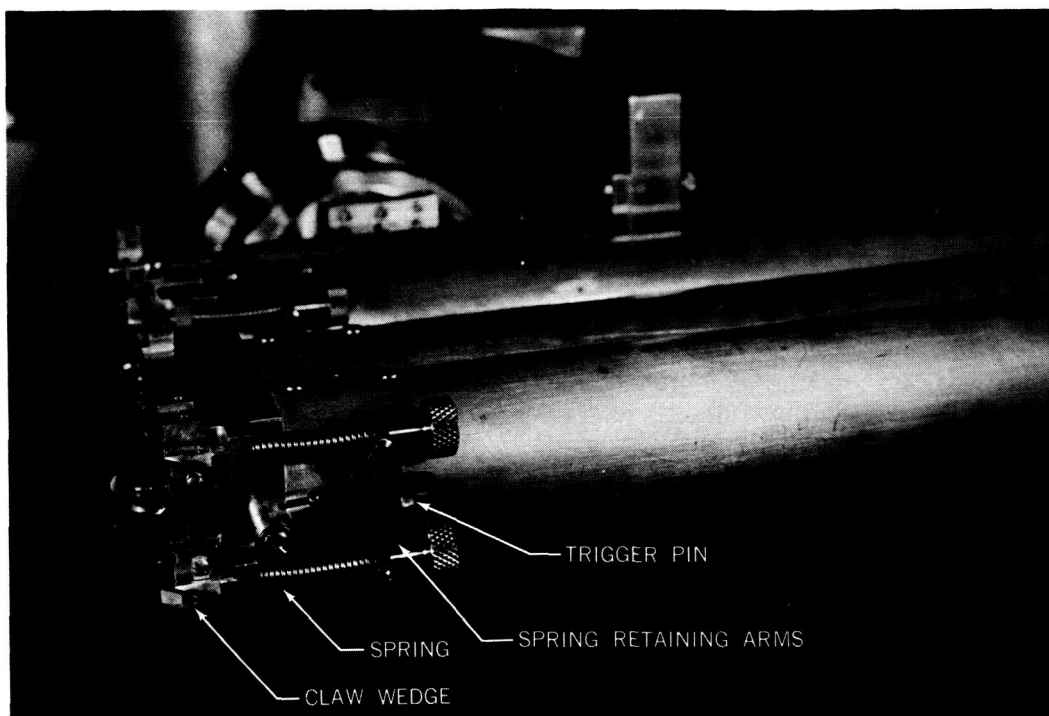


Figure 5—Triggered knuckle lock cocked.

retaining arms these arms release compressed springs. However, just before the springs are released, the "T" catch on "B" knuckle drops over the wedge on the claws on "A" knuckle. When the springs are released, they pull the claws which wedge in slots of the "T" catch, closing the knuckle and firmly locking it. The knuckles are guided into place by a tapered pin in "A" knuckle which wedges into a hole in "B" knuckle. The "B" knuckle is also positioned and locked by the wedge of the claw seating in the "T" catch. The "T" catch itself is wedged into place in the "B" knuckle. An additional feature of this design is that only about 5 lb of tripping force is required to bring 100 pounds of locking force into play.

A sequencing device attached to the side of the knuckle works in a similar way. It begins to actuate as the knuckles close and pushes a pin. This pin moves a slotted block off a hook attached to the next section to open. This release occurs just as the knuckle is locked. A microswitch is built into each knuckle to signal when the joint is closed.

MOTORS

Either of two motors are used for operating this boom, depending on the particular case.

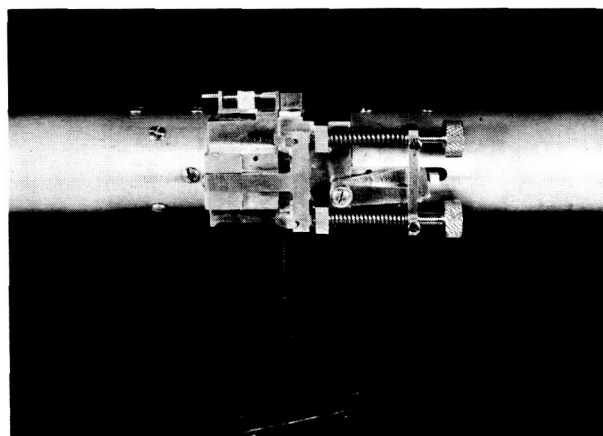


Figure 6—Triggered knuckle lock in closed position.

Figure 7 shows a completely nonmagnetic spring motor developed specifically for this application. Its governed output supplies sufficient torque to open a four section boom with a bundle of 46 electrical wires at 0°F. Electric dimple motors are used for starting the mechanism. The total weight of the assembly is less than 2 lb.

The other motor which has been used is a 24 volt, wound field dc motor (Figure 8). It requires about 25 watts and weighs 15 ounces. The permanent magnetic field of this motor is 72 gammas at 1 foot. If magnetic contamination is not a problem, an even lighter, permanent magnet dc motor can be used.

WEIGHT

The data in Table 1 is given in order that an estimate can be made on the weight of a particular boom. A four section, 25 foot boom using 1 inch diameter aluminum tubing would weigh 4.4 lb with an electric motor and 5.4 lb with a spring motor.

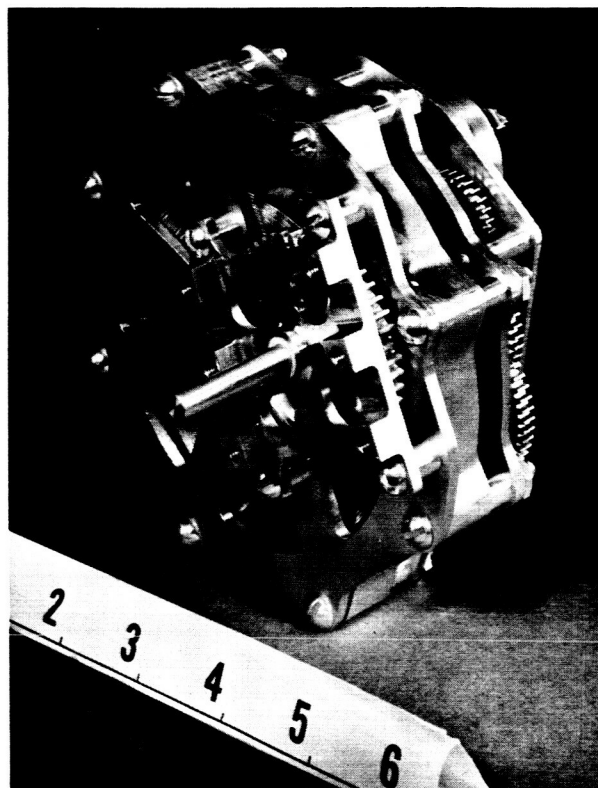


Figure 7—Nonmagnetic, constant speed spring motor.
(The measurement is in inches.)

Table 1

Boom Instrumentation

Item	Material	Weight
Knuckles	Aluminum	0.35 lb each
Tubes	Aluminum, 1-1/2 in. O.D. x 0.020 in. wall	0.11 lb/ft
	Aluminum, 1 in. O.D. x 0.020 in. wall	0.074 lb/ft
Spring motor	Aluminum, magnesium, and elgiloy	2 lb
dc motor (wound field)		0.94 lb
Spacecraft interface and motor mounting pad	Aluminum	0.25 lb

EXPERIMENTAL BOOM

The 12 foot, three section boom shown in the photographs was built for determining the torques required for such a boom, with the electrical cable passing through the joints, to unfold, and for determining the relative horizontal (axial) position accuracy of the boom. The sections are 1-1/2 in. O.D. aluminum tubes with a 0.020 in. wall. The spring motor shown in these pictures is an earlier version that was hermetically sealed. Present knowledge of lubricants and the brief operational life of the motor eliminates the need for the seal.

As a result of having the knuckle powered by an external source there is sufficient clearance to allow passage of a large electrical cable through the knuckle. This results in a more compact design and the best way for securing the cable loop against launch vibration. Thermal control of the electrical cable is also facilitated by this feature.

The electrical cable used in this boom consisted of 33 strands of No. 20 Teflon-covered wire and 13 No. 22 shielded strands. Figure 4 shows the cable passing through the knuckles when the boom is in the folded condition, and Figure 9 shows its position when the boom has unfolded. This cable weighed 1/4 lb/ft and was lashed to an aluminum strip fastened to the tubing. The purpose of this strip was to secure the electrical cable during vibration.

To provide a completely nonmagnetic boom, all springs and the wire cable were made of elgiloy, and all other parts were aluminum. This was also true for the spring motor. The small residual magnetic field of the wound field dc motor would be negligible to a magnetometer placed 25 feet away.

The boom is supported by castors attached to the pivot bushing of each joint and high enough to allow the sphere to clear the ground. The sphere on the end of the boom is a bias sphere for a rubidium vapor magnetometer.

Tests using the spring motor shown in Figure 7 were run for determining the torque required to open the boom at different temperatures. However, the data obtained were inaccurate because of the opposing torque introduced by the friction of the castors and their 4 foot moment arm. Below 0°F the castors sometimes failed to

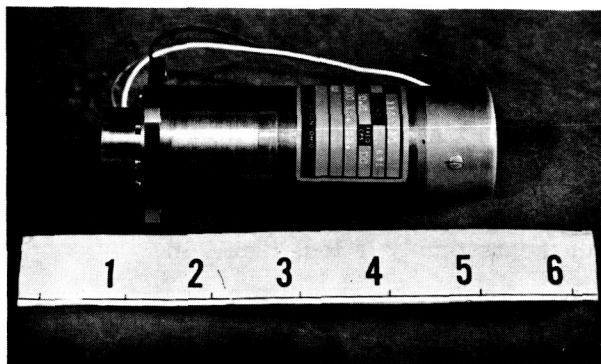


Figure 8—Wound field dc motor. (The measurement is in inches.)

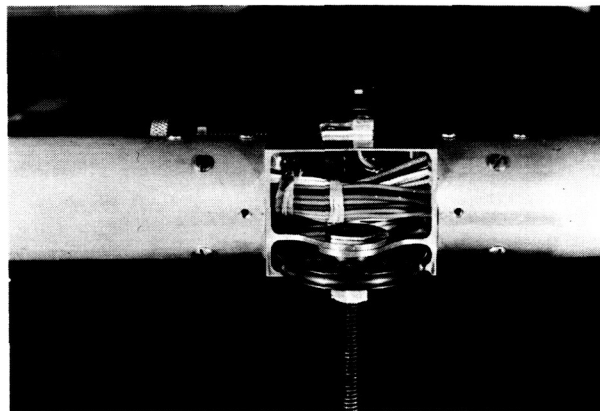


Figure 9—Electrical cable passage through the closed knuckle.

align in the direction of motion. Even with this handicap, the spring motor was capable of extending the boom. The load presented by the electrical cable pack was also extreme, since an actual experiment would use No. 26 or 28 wire for the purpose of saving weight.

Because of the problems encountered with the castors, it was impossible to make the desired accuracy checks. A system to perform such a test has been developed in which a boom is supported by air bearings on an exceptionally smooth surface; but this is not yet available at the Goddard Space Flight Center.

Nevertheless, a study of the knuckle design indicates that such a deployed boom is structurally a solid member. Therefore, the tip position will be precisely repeatable when the boom is in equilibrium under similar external forces, provided the boom has not been stressed beyond the elastic limit.

This points out the main advantage of a cable-driven boom. Since it deploys at a slow, constant speed, the bending moment imposed on the boom by the sudden stop of the last knuckle is much lower than that caused by a spring-driven boom, which is continuously accelerating until stopped. For this reason a cable-driven boom can be lighter or can support a larger experiment than a spring-driven boom.

CONCLUSION

Because of its ability to precisely orient, the boom system described in this report is suitable for use on a highly stabilized space platform whose attitude, in relation to some known reference, can be accurately determined. The basic design can also be applied in the construction of a boom to place other instruments, such as antennas and solar-celled paddle systems, away from the main body of a spacecraft.